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ABSTRACT

This physics course covers the following main subject areas: (1) liquids; (2) pressure; (3) liquid flow; (4) temperature and heat; and (5) electric currents. The prerequisites for understanding this material are basic algebra and geometry. The lessons are composed mostly of sample problems and calculations that water and wastewater operators have to make. The examples are followed by practice problems. Each lesson concludes with an additional reading list. (BB)

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PHYSICS FOR WATER AND WASTEWATER OPERATORS

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This course covers some of the main concepts of Physics that relate to the water and wastewater field. The subject areas covered are:

Liquids

a. Specific gravity

b. Specific weight and density pressure

Pressure
(Pressure due to height)
Liquid Flow

a. Rate of flow

b. Continuity principle

c. Bernoulli's Theorem

d. Flow measurement (Venturi meter)

e. Friction loss

Temperature and Heat

a. Fahrenheit/Celsius scales

b. British Thermal Units

c. Specific heat

Electric Currents

a. Current (Amperes)

b. Resistance

c. Voltage

d. Converting electric current to mechanical power

1. Watts/Kilowatts

2. Horsepower

3. Motor efficiency

The pre-requisites necessary to accomplish this course in Physics for Water and Wastewater Technology are:

1. Basic Algebra
2. Geometry
   a. Areas
   b. Volumes

The concepts covered in the section liquids are:

1. Specific gravity
2. Specific weight
3. Density

These concepts are prevalent in water and wastewater technology in such areas as:

1. Liquid flow
2. Changes in applied pressure
3. Pump performance

LIQUIDS

Liquids are substances that have definite size but take the shape of their container. Liquids have specific properties. These properties distinguish each type of liquid from another liquid.

Specific Gravity

One such property is specific gravity. The specific gravity is a pure number, that means it has no unit value.

Example: 5 cubic feet, 2 pounds, 15 gallons. Cubic feet, pounds, gallons are unit values; therefore, a pure number is 5 or 2 or 15.

Specific gravity is a number that indicates if a substance is lighter or heavier than an equal volume of pure water.

Example 1: The specific gravity of cast iron is 7.05. This means that a volume of cast iron is 7.05 times heavier than the same volume of water.

Example 2: Lubricating oil has a specific gravity of 0.870. This means that a volume of oil is 0.87 times "heavier" than the same volume of water. But since water has a specific gravity of 1 g., therefore, oil is lighter than water.

Specific gravity is a factor that effects the flow of liquids. Although in water and wastewater the specific gravity does not change drastically (a range of 1.00 to 1.08). It is taken into consideration when water and wastewater is to be pumped, or the weight of the liquids is needed.

Specific gravity is more of a factor in wastewater since the solids in wastewater do change the weight of the wastewater and therefore the change in specific gravity.

Specific gravity is defined as a ratio between the weight of a substance with a specific volume and the weight of pure water with an equivalent volume.

Problem

A tank full of pure water weighs 1200 lbs. How much would that same tank weigh if the contents had wastewater with a specific gravity of 1.03?

Solution

Weight of pure water x specific gravity = weight of wastewater.

1200 x 1.03 = 1236 lbs.

Problem

If the weight of pure water is 7500 lbs. The weight of the same volume of wastewater is 7875 lbs. Calculate the specific gravity of the wastewater.

Solution

$$\text{Specific gravity} = \frac{\text{weight of wastewater}}{\text{Weight of pure water}}$$

$$\text{sp. gr.} = \frac{7875 \text{ lbs.}}{7500 \text{ lbs.}} = 1.05$$

Specific Weight and Density

Another characteristic of liquids is specific weight (sp. wt.) and density (d). Specific weight (sp. wt.) is a value obtained by dividing the weight of the liquid by its volume. Density is a value obtained by dividing the mass of the liquid by its volume.

Density is a value that indicates if a substance is denser (heavier) than another substance. The proper unit expressing density is slugs/ft.^{3}.

Example: Lead has a density of 22.0 slugs/ft.^{3} while pure water has a density of 1.94 slugs/ft.^{3}. Therefore, lead is denser than pure water. Suppose the density of a substance lubricating oil is 1.75 slugs/ft.^{3}. Then oil is less dense than pure water since pure water has a density of 1.94 slugs/ft.^{3}.

By knowing the density (d) of a substance the specific gravity of the substance can be calculated.

$$\text{Specific gravity} = \frac{\text{density of substance}}{\text{density of pure water}}$$

Example: The density of alcohol is 1.53 slugs/ft.^{3}. The density of water is 1.94 slugs/ft.^{3}. What is the specific gravity of alcohol.

Solution

$$\text{sp. gr.} = \frac{da}{dw} = \frac{1.53 \text{ slugs/ft.}^3}{1.94 \text{ slugs/ft.}^3}$$

$$\text{sp. gr} = 0.79$$

sp. gr. = specific gravity

da = density of alcohol

dw = density of pure water

Example: The specific gravity of a wastewater sample is 1.08. What is the density (dww) of the wastewater.

Solution

$$\text{sp. gr.} = \frac{dww}{dw}$$

$$dww = \text{sp. gr.} \times dw$$

$$= 1.08 \times 1.94 \text{ slugs/ft.}^3$$

$$dww = 2.095 \text{ slugs/ft.}^3$$

sp. gr. = specific gravity

dww = density of wastewater

dw = density of pure water

Since density is a value obtained from the mass of the substance, the definition of mass is a measure of resistance a substance has to change in its motion. The resistance that has to be overcome,is the "quantity of matter" in the substance.

It is easier to push a small car than a large truck into motion. What is uneven is not the force applied by the person pushing but the quantity representing the car and truck. Now most confuse mass and weight. Though both concepts are interconnected, mass is amount, and weight is the amount of gravitational pull applied to the substance. That is weight is the force with

which a substance is attracted towards the center of earth. The unit of measure is pounds (lbs.).

To calculate specific weight, the weight of a substance is divided by its volume.

$W = \frac{w}{V}$

W = specific weight lbs/ft.^{3}

w = weight lbs.

V = volume ft.^{3}

Specific gravity is also a function of specific weight, the formula:

sp. gr. = $\frac{Ws}{Ww}$

sp. gr. = specific gravity

Ws = specific weight of substance

Ww = specific weight of water (62.4 lbs./ft.^{3})

To calculate density using mass and volume, divide the mass of a substance by its volume.

$d = \frac{m}{V}$

d = density slugs/ft.^{3}

m = Mass slugs

V = Volume ft.^{3}

To calculate weight (w) multiply mass (m) with gravitation force (g) or acceleration of gravity. The value of (g) is constant. It is 32. ft./sec.^{2}

$w = m \times g$

w = weight lbs.

m = Mass

g = acceleration of gravity

Problems

Example: 1.336 cubic feet of water weighs 83.4 lbs. Calculate specific weight.

Solution

$$W = \frac{w}{v} = \frac{83.4 \text{ lbs.}}{1.336 \text{ ft.}^3} = 62.4 \text{ lbs/ft.}^3$$

Example: A volume of oil weighs 1.90 lbs. The specific weight of the oil is 54.2 lbs/ft.^{3} Calculate the volume in cubic feet.

Solution

$$W = \frac{w}{V}$$

$$W \times V = w$$

$$V = \frac{w}{W} = \frac{190 \text{ lbs.}}{54.2 \text{ lbs./ft.}^3} = \frac{190 \text{ lbs. x ft.}^3}{54.2 \text{ lbs.}} = 3.51 \text{ ft.}^3$$

$$V = \frac{190 \text{ lbs. x ft.}^3}{54.2 \text{ lbs.}}$$

$$V = 3.51 \text{ ft.}^3$$

Example: The specific gravity of sludge from the secondary treatment is 1.03. The volume is 8500 ft.^{3}

Calculate:

1. The weight of the sludge.
2. The density of the sludge.

Solution

1. The solution to this part of the problem depends upon combining two formulas:

   a. sp. gr. = $\frac{Ws}{Ww}$

   sp. gr. = specific gravity

   Ws = specific weight of sludge lbs./ft.^{3}

   Ww = specific weight of pure water (62.4 lbs./ft.^{3}

b. $Ws = \frac{w}{V}$

Ws = specific weight of sludge lbs./ft.^{3}

w = weight of sludge

V = volume of sludge

Now combine a & b

sp. gr. $= \frac{Ws}{Ww}$ $\qquad Ws = \frac{w}{V}$

sp. gr. $= \frac{\frac{w}{V}}{Ww} = \frac{w}{V \times Ww}$

Since the question is to find the weight of the sludge, the working solution is:

w = sp. gr. x V x Ww

Substituting values and units:

$w = 1.03 \times 8500$ ft.^{3} x 62.4 lbs/ft.^{3} = 546312 lbs.

2. Again the solution is a combination of formulas:

a. $d = \frac{m}{V}$

d = density slugs/ft.^{3}

m = mass slugs

v = Volume ft.^{3}

b. $w = m \times g$

w = weight lbs.

m = mass

g = gravity 32 ft. sec.^{2}

Therefore:

$m = \frac{w}{g}$

Now the combination of a & b

$d = \frac{m}{V}$ and $m = \frac{w}{g}$

$d = \frac{\frac{w}{g}}{V} = \frac{w}{g \times V}$

Substitute values and units

$$d = \frac{546312 \text{ lbs.}}{32 \text{ ft./sec.}^2 \times 8300 \text{ ft.}^3} = \frac{2.0 \text{ lbs.}}{\text{ft./sec.}^2 \times \text{ft.}^3}$$

A slug has a unit measurement in:

$$\frac{\text{lb.}}{\text{ft./sec.}^2}$$

Therefore, the answer is 2.0 slugs/ft.^{3}

Glossary

Density: Defined as mass per unit volume. Expressed in slugs/ft.^{3}. Symbol (d).

Specific gravity: Defined as the ratio between the density of a substance to that of water. Expressed as a pure number. Symbol (sp. gr.).

Specific weight: Defined as weight per unit volume. Expressed in lbs./ft.^{3}. Symbol (W).

Mass: Defined as the quantity of matter a substance contains. Expressed in slugs. Symbol (m).

Weight: Defined as the force with which the mass is attracted towards the center of the earth. Expressed in lbs. Symbol (w).

Slug = A British system expressing mass. Expressed in $\frac{\text{lb.}}{\text{ft./sec.}^2}$

Problems

1. The volume of sludge in a sludge thickening process is 2200/ft.^{3} The sludge has a specific weight of 1.06. Calculate the weight of the sludge.

2. A digestor has the dimension 25 ft. height, and a diameter of 20 ft. The sludge has a specific gravity of 1.03. Calculate the weight of the sludge. Use 1 $ft.^3$ = 62.4 lbs.

3. The volume of wastewater is 175000 gallons. The weight of pure water of equal volume is 23164 lbs. Calculate the specific gravity. Use 1 $ft.^3$ = 7.48.

4. A block of wood has a volume of 55.58 $ft.^3$ and a weight of 1814 lbs. What is its specific weight.

5. The weight of wastewater is 5122 lbs. The same volume of pure water weighs 4832 lbs. Calculate the specific gravity.

6. The volume of sludge is 52.08 $ft.^3$ The weight of the sludge is 3500 lbs. Calculate the density of the sludge.

Additional Reading

Ewen, Nelson, Schurter, McFadden, Physics for Career Education, Prentice Hall Publishers, Chapter 14 and 15

Subject Areas of Interest

1. Specific Gravity
2. Specific Weight
3. Mass
4. Density

The concept covered in the section pressure is:

Liquid pressure

This concept is prevalent in the water and wastewater technology in such areas as:

1. Liquid flow
2. Total dynamic head
3. Pump performance

PRESSURE

As a plant operator one must be concerned with the movement of water and wastewater to and from the user. Since water and wastewater are liquids and that liquids have a definite size, then it stands to reason that liquids can be acted upon by gravitation pull. This pull is a force that is measured in pounds (lbs.) & is the weight of the liquid.

Force is defined as the weight of the substance. Pressure is defined as the force applied to a unit area.

Example: If an object weighs 100 lbs., then it is applying a force of 100 lbs. But if this object is placed on a stand 4 square inches then the pressure applied by the object is 25 lbs./in.^{2} (pounds per square inch) (psi).

The formula for pressure therefore is force (weight) divided by area.

$$P = \frac{w}{A}$$

P = Pressure lbs./in.^{2}

w = Weight lbs.

A = Area

Example 1: A weight of 3000 lbs. is placed on a table that has an area of 300 square inches. Calculate the pressure exerted by the object.

Solution

$$P = \frac{w}{A}$$

$$= \frac{3000 \text{ lbs.}}{300 \text{ in.}^2}$$

$$= 10 \text{ lbs./in.}^2$$

P = Pressure lbs./in.^{2}

w = Weight lbs.

A = Area in.^{2}

Example 2: An object weighs 200 lbs. It is placed on a table that has the dimensions 12 x 6 inches. Calculate pressure exerted by the object on the table.

Solution next page

Solution

$$P = \frac{w}{A}$$

$$= \frac{w}{L \times W}$$

$$= \frac{200 \text{ lbs.}}{12 \times 6 \text{ in.}^2}$$

$$= 2.8 \text{ lbs./in.}^2$$

Example 3: A column of water weighs 1300 lbs. The base of the column has an area 26 square inches. Calculate the pressure on the base of the column.

Solution

$$P = \frac{w}{A}$$

$$= \frac{1300 \text{ lbs.}}{26 \text{ in.}^2}$$

$$= 50 \text{ lbs./in.}^2$$

Example 4: A column of water weighs 1300 lbs. The base of the column has an area of 20 square inches. Calculate the pressure on the base of the column.

Solution

$$P = \frac{w}{A}$$

$$= \frac{1300 \text{ lbs.}}{20 \text{ in.}^2} = 65 \text{ lbs./in.}^2$$

By comparing Example 3 and Example 4 one observes that the weight is the same but that the area changes from 26 square inches to 20 square inches. This change, changed the pressure applied.

Example: A column of water weighs 7500 lbs. and the area of the base of the column is 75 square inches.

1. What is the pressure applied on the base.
2. What would the new pressure be if the weight of the water was changed to 1500 lbs.

Solution

1. $P = \frac{w}{A}$

   $= \frac{7500 \text{ lbs.}}{75 \text{ in.}^2} = 100 \text{ lbs./in.}^2$

2. $P = \frac{1500 \text{ lbs.}}{75 \text{ in.}^2} = 20 \text{ lbs./in.}^2$

Since most liquid volumes are too large to weigh the formula to use to calculate pressure is:

$P = h \times w$

P = Pressure psi

h = Height of liquid column

w = Specific weight of the liquid

By combining two formulas one can see how the above formula can be obtained.

a. $P = \frac{w}{A}$

P = Pressure

w = Weight

A = Area

Therefore

$w = P \times A$

b. $W = \frac{w}{V}$

W = Specific weight

w = Weight

V = Volume

Therefore

$w^2 = W \times V$

By combining a & b

$W = P \times A$ and $h = W \times V$

Therefore

$P \times A = W \times V$

Since

$V = A \times h$

V = Volume

A = Area

h = Height

Then

$P \times A = W \times A \times h$

Reorganizing the formula to calculate for P

$$P = \frac{W \times A \times h}{A}$$

Therefore

$P = W \times h$

Since the pressure is a function of height, (the specific weight of water is 62.4 lbs./ft.^{3}) one can be able to determine the pressure applied by water at any given height.

Example 1: A water column is 100 ft. high

1. What is the pressure at the 10 ft. mark from the top.
2. What is the pressure at the 50 ft.
3. What is the pressure at the base of the column.

Solution

1. $P = W_w \times h$

P = Pressure lbs./in.^{2}

W_w = Specific gravity of water 62.4 lbs./ft.^{3}

h = Height ft.

$$P = \frac{62.4 \text{ lbs.}}{\text{ft.}^3} \times 10 \text{ ft.}$$

$$P = \frac{62.4 \text{ lbs.}}{\text{ft.}^2}$$

Since pressure unit is lbs./in.^2 (psi)

Therefore

$$P = \frac{62.4 \text{ lbs.}}{\text{ft.}^2} \times \frac{\text{ft.}^2}{144 \text{ in.}^2}$$

$$= 4/34 \text{ lbs/in.}^2$$

2. $P = W_w \times h$

$$= \frac{62.4 \text{ lbs.}}{\text{ft.}^2} \times 50 \text{ ft.} \times \frac{\text{ft.}^2}{144 \text{ in.}^2}$$

$$= 21.7 \text{ lbs./in.}^2$$

3. $P = W_w \times h$

$$= \frac{62.4 \text{ lbs.}}{\text{ft.}^2} \times 100 \text{ ft.} \times \frac{\text{ft.}^2}{144 \text{ in.}^2}$$

$$= 43.4 \text{ lbs./in.}$$

One will notice from the examples that the specific weight is provided in lbs./ft.^3 and height in ft., therefore, pressure is in lbs./ft.^2 but the usual pressure unit in water and wastewater technology is in lbs./in.^2 (psi), thereby changing square ft. (ft.^2) to square inches (in.^2)one will obtain psi. So one can find a constant since the specific weight of water (being 62.4 lbs./ft.^3) and one (1) square foot (ft.^2) equals 144 square inches the constant obtained by dividing 62.4 lbs./ft.^3 by 144 ft.^2 a value of .434 lbs./ft. is obtained.

$$\frac{62.4 \text{ lbs.}}{\text{ft.}^3} \times \frac{\text{ft.}^2}{144 \text{ in.}^2} = \frac{.434 \text{ lbs.}}{\text{ft.} \times \text{in.}^2}$$

The pressure formula can be simplified.

$$P = \frac{.434 \text{ lbs.}}{\text{ft.} \times \text{in.}^2} \times h \text{ (ft.)}$$

$$= \frac{.434 \text{ lbs.}}{\text{in.}^2} \times h$$

Therefore, pressure of water is a product of a constant .434 and the height of the water column.

Example: A water column is 100 ft. high.

1. Calculate the pressure at the 10 ft. mark from top.
2. Calculate the pressure at the 50 ft. mark.
3. Calculate the pressure at the base.

Solution

1. $P = .434 \times h$

   $= .434 \times 10$

   $P = 4.34$ psi

2. $P = .434 \times h$

   $= .434 \times 50$

   $= 21.7$ psi

3. $P = .434 \times h$

   $= .434 \times 100$

   $= 43.4$ psi

Glossary

Pressure: A function of force divided by area. The amount of force (w) applied to a specific area ($in.^2$). Expressed in pounds per square inch ($lbs./in.^2$) or psi. Symbol (P).

$$P = \frac{w}{A}$$

P = Pressure $lbs./in.^2$

w = Weight lbs.

A = Area square in.

Also: Pressure (P) in water and wastewater is a function of the height (h) the water column is and the specific weight of the water.

P lbs./in.^{2} = 0.434 x h (ft.)

P = Pressure lbs./in.^{2}

0.434 constant for water only

h = Height (ft.)

Problems

1. What is the pressure at the bottom of a tank that contains 170,000 lbs. of water. The base of the tank is 185 square inches.

2. A water column with a radius of 10 ft. is filled with water. The pressure indicator shows 100 psi.

(a) What is the weight of the water?

(b) What is the height of the water column?

3. What is the pressure applied on the bottom of a rectangular tank 10.0 ft. by 5.00 ft. by 4 ft. deep.

4. A water line in a tower stands 125 feet high. What is the pressure exerted by the water at the base of the tower.

Additional Reading

Ewen, Nelson, Schurter, McFadden, Physics for Career Education, Prentice Hall Publishers, Chapters, 3, 9, 14 and 15.

Subject Areas of Interest

1. Areas
2. Volumes
3. Mass
4. Weight
5. Pressure
    a. Gauge
    b. Atmosphere

The concepts covered in the section liquid flow are:

1. Rate of flow
2. Continuity principle
3. Bernoulli's equation
4. Venturi meter
5. Friction

These concepts are prevalent in the water and wastewater technology in such areas as:

1. Liquid transmission
2. Liquid quantity
3. Flow measurement
4. Settling rates
5. Pump performance
6. Power cost

LIQUID FLOW

A concept important in Water and Wastewater Technology is liquid flow. Several concepts make up the flow.

1. Rate of Flow

The definition of the rate of flow is the volume of water delivered in a unit time. That means if a volume of 100 cubic feet of water is delivered in 5 seconds, the rate of flow is 20 ft.^{3}/sec. That is 20 cubic feet of water in one (1) sec. was being delivered.

Therefore, to be able to obtain rate of flow (Q), the formula to use is:

$$Q = \frac{V}{t}$$

Q = Rate of flow (ft.^{3}/sec.)

V = Volume ft.^{3}

t = Time sec.

The difficulty is that one usually does not know the volume of water delivered neither the time it took to deliver. Therefore a new direction should be explored.

Since we know that volume (V) is equal to Area x Distance (s)

Then by substituting in the formula

$$Q = \frac{V}{t}$$

The equation is transformed to

$$Q = \frac{A \times s}{t}$$

Q = Rate of flow ft.^{3}/sec.

A = Cross sectional area of pipe ft.^{2}

s = Distance ft.

t = Time sec.

Now suppose a car traveled at a speed (velocity) of 55 miles per hour (MPH) for 1 hour (H). How far did the car travel? Ans. 55 miles. Or if a car traveled at a velocity (speed) of 55 MPH for 3 hours, how far did it travel? Ans. 165 miles.

The formula used was

Distance (s) = Velocity (v) x time (t)

$s = v \times t$

Example 1

$$s = \frac{55 \text{ miles}}{\text{hour}} \times 1 \text{ hour}$$

$$= 55 \text{ miles}$$

Example 2

$$s = \frac{55 \text{ miles}}{\text{hour}} \times 3 \text{ hours}$$

$$= 165 \text{ miles}$$

Since one does not know the distance water traveled through the pipe (due to the fact that the pipe is buried and therefore the length is not known)

By substituting in the formula

$$Q = \frac{A \times s}{t}$$

The value of s

The new formula is

$$Q = \frac{A \times v \times t}{t}$$

Q = Rate of flow

A = Cross sectional area of pipe

v = Velocity of water

t = Time

Since time is in the numerator and denominator of the equation, the formula for the rate of flow is

$Q = A \times v$

Q = Rate of flow $ft.^3/sec.$

A = Cross sectional area of pipe $ft.^2$

v = Velocity of flow of water through the pipe (ft./sec.)

Example 1

Water flowing through a pipe with a diameter of 1 foot, has a velocity of 3 ft./sec. What would be the rate of flow?

Solution

$Q = A \times v$

$Q = .785 \times D^2 \times v$

$= .785 \times (1)^2 \times 3$ ft./sec.

$= .785 \times 1$ ft.$^2 \times 3$ ft./sec.

$= 2.36$ ft.^{3}/sec.

Example 2

Water flowing through a pipe with a diameter of 7 inches, has a velocity of 4 ft./sec. Calculate rate of flow.

$Q = A \times v$

$= .785 \times D^2 \times v$

$= .785 \times (7/12)^2 \times 4$ ft./sec.

$= .785 \times .34$ ft.$^2 \times 4$ ft./sec.

$= 1.07$ ft.^{3}/sec.

Since water distribution systems are composed of different size pipes, the continuity principle will apply.

The continuity principle states that a volume of liquid entering the pipe at one end per unit time, must leave the other end in the same time. If the principle did not apply then if less liquid leaves the pipe than enters it, the volume will build up and the pipe will break. If more liquid leaves the pipe than enters it, the pipe will eventually empty.

Assuming that a series of pipes were connected then from the continuity principle

$Q_1 = Q_2 = Q_3 = Q_4$

Substituting for Q

$Q_1 = A_1v_1$

$Q_2 = A_2v_2$

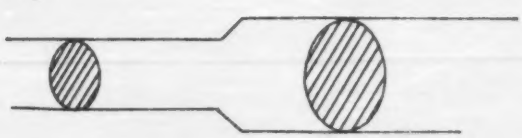
$Q_3 = A_2v_2$

$Q = A_2v_2$

Therefore

$A_1v_1 = A_2v_2 = A_3v_3 = A_4v_4$

Example: Two pipes, one 4 inches in diameter, the second 6 inches in diameter joined (See Diagram).



The direction of flow is from the 4 in. to the 6 in. The velocity of the water is 8 ft./sec.

1. Calculate the flow rate
2. Calculate the discharge velocity

Solution:

Since the flow rate through the 4 in. pipe is equal to the flow rate in the 6 in. pipe then

$Q = Q_2$

$Q = A_1 v_1$

$= .785 \times D^2 \times v$

$= .785 \times (4/12 \text{ ft.})^2 \times 8 \text{ ft./sec.}$

$= .785 \times 16/144 \times 8$

$Q = .7 \text{ ft.}^3/\text{sec.}$

Now that the flow rates through both pipes are equal, then

$Q^2 = A_2 v_2$

$Q = .785 \times D^2 \times v$

$.7 \text{ ft.}^3/\text{sec.} = .785 \times (6/12 \text{ ft.})^2 \times v$

$.7 \text{ ft.}^3/\text{sec} = .785 \times 36/144 \text{ ft.}^2 \times v$

$$v = \frac{.7 \text{ ft.}^3/\text{sec} \times 144}{.785 \times 36 \text{ ft.}^2}$$

$= 3.57 \text{ ft./sec.}$

The concept of rate of flow not only is workable in closed pipes that are full, but also in open channel and partially full. (See diagram).

Therefore, rate of flow in channels in a partially full pipe is the product of the cross-sectional area of the channel and the velocity of flow of liquid. The cross-sectional area has to be perpendicular to the direction of flow.

That means that

$Q = A \times v$

Q = Rate of flow ft.^{3}/sec.

A = Cross-sectional area ft.^{2}

v = Velocity ft./sec.

Assuming that a channel has the dimensions 200 ft. long, 2 ft. wide, and the liquid height in the channel to be 1.5 ft. The velocity of the flow is 3 ft./sec.

The direction of flow is through the length of the channel.

1. Calculate the rate of flow (Q)

Solution

$Q = A \times v$

We know that area (A) has to be perpendicular to the direction of flow, and that the direction of flow is through the length; therefore,

A = Width x liquid height

A = 2 ft. x 1.5 ft.

A = 3 ft.^{2}

Now

$Q = A \times v$

$= 3 \text{ ft.}^2 \times 3 \text{ ft./sec.}$

$= 9 \text{ ft.}^3/\text{sec.}$

The rate of flow through any channel that may be partially full, completely full, open channel or closed channel is defined as the volume of liquid delivered in a unit of time.

Problem 1: What is the rate of flow of wastewater if the channel is 4 feet wide, the water depth is 1 foot and the velocity is 0.97 ft./sec.

Solution

$Q = Av$

$Q = 4 \text{ ft.} \times 1 \text{ ft.} \times 0.97 \text{ ft./sec.}$

$= 3.88 \text{ ft.}^3/\text{sec.}$

Problem 2: A grit chamber has dimensions 25 ft. long, 6 ft. wide and 3 ft. deep. The flow direction is through the length. The velocity is .8 ft./sec. What is the flow rate?

1. When the water depth 1 ft.
2. When the water depth 2.5 ft.

Solution

1. Since the direction of flow is through the length; therefore, the cross sectional area is the width x the water depth.

1. $Q = Av$

$= 6 \text{ ft.} \times 1 \text{ ft.} \times .8 \text{ ft./sec.}$

$= 4.8 \text{ ft.}^3/\text{sec.}$

2. $Q = Av$

$= 6 \text{ ft.} \times 2.5 \text{ ft.} \times .8 \text{ ft./sec.}$

$= 12 \text{ ft.}^3\text{/sec.}$

Problem 3: An open channel with a cross-sectional area of 10 ft.^2 The rate of flow of water is 20 ft.^3/sec. Calculate the velocity of the water.

Solution

$Q = Av$

or $V = \frac{Q}{A}$

$V = \frac{20 \text{ ft.}^3\text{/sec.}}{10 \text{ ft.}^2}$

$= 2 \text{ ft./sec.}$

2. Bernoulli's Equation

To fully understand the origin of Bernoulli's equation one must be familiar with the concept of work and energy which will not be covered in this portion of the course.

Bernoulli's equation is obtained from a combination of potential and kinetic energies, and static pressure. These energies contribute to the total overall pressure exerted by the liuqid system; therefore,

1. Potential head (Pot. hd.) is the potential energy divided by the weight of the liquid.

$$(\text{Pot. hd.}) = \frac{Wh}{W} = h$$

2. Velocity head (Vel. hd.) is the kinetic energy of the system divided by the weight of the liquid.

$$(\text{Vel hd.}) = \frac{\frac{1}{2}\left(\frac{w}{g}\right)v^2}{W} = \frac{v^2}{2g}$$

3. Pressure head of static head (Pres. hd.) is the energy exerted by the liquid as a consequence of its pressure. Since

$P = h \times W$

P = Pressure

h = Height

W = Specific weight

Therefore

$h = \frac{P}{W}$

As previously mentioned, Bernoulli determined that at any point in a liquid system, the sum of these three energies was constant (principle of conservation of energy).

Therefore,

$K = h + \frac{v^2}{2g} + \frac{P}{W}$

K = Constant

h = Height of liquid ft.

v = Velocity ft./sec.

g = Gravitational pull (32 ft./sec.^{2})

P = Pressure psi

W = Specific weight lbs./ft.^{3}

Now since in a pipe system where the pipe is not uniform size, Bernoulli's theory is applicable to the different sizes.

Since K_1 of smaller pipe is equal to K_2 of the larger size pipe

$K_1 = K_2$

Then

$h_1 + \frac{v_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{v_2^2}{2g} + \frac{P_2}{W}$

By utilizing Bernoulli's theorem one will be able to see that a change in pipe size will change the velocity; therefore, a change in pressure.

Let us for simplification purposes assume that h_1 and h_2 are equal

So by $h_1 = h_2$

Bernoulli's formula becomes

$$\frac{v_1^2}{2g} + \frac{P_1}{W} = \frac{V_2^2}{2g} + \frac{P_2}{W}$$

Now

$$\frac{P_1}{W} - \frac{P_2}{W} = \frac{V_2^2}{2g} - \frac{V_1}{2g}$$

So

$$\frac{P_1 - P_2}{W} = \frac{V_2^2 - V_1^2}{2g}$$

$$P_2 = P_1 - \frac{W}{2g}(v_2^2 - V_1^2)$$

Now let us review the continuity principle

$$Q_1 = Q_2$$

$$A_1v_1 = A_2v_2$$

That is the velocity is greater through a smaller diameter pipe than a larger diameter pipe. Assuming that v_2 is the velocity through the smaller pipe by reviewing the formula

$$P_2 = P_1 - \frac{W}{2g}(v_2^D - v_1^2)$$

One will notice that P_2 (the pressure in the smaller diameter pipe will be less than the pressure (P_1) in the larger diameter pipe.

The use of Bernoulli's theory is important in flow measurement using a Venturi meter.

The Venturi meter is an instrument used for the very accurate measurement of full fluid flow under pressure. The meter functions by reducing the area of flow, the increase in velocity and decrease in pressure can be measured and translated to flow rate (Quantity)(Q).

By starting with Bernoulli's theory

$$h_1 + v_1^2 + \frac{P_1}{W} = h_2 + \frac{v^2}{2g} + \frac{P_2}{W}$$

Since the meter has no liquid static head that is (h) then h_1 is equal to h_2.

Therefore,

$$\frac{P_1}{W} + \frac{v_1^2}{2g} = \frac{P_2}{W} + \frac{v_2^2}{2g}$$

Now

$$\frac{P_1}{W} - \frac{P_2}{W} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

$$\frac{(P_1 - P_2)\,2g}{W} = v_2^2 - v_1^2$$

Since $Q = vA$

and

$v = \frac{Q}{A}$

Q = Rate of flow

v = Velocity

A = Cross-sectional area

Then

$$\frac{2g}{W}(P_1 - P_2) = \frac{Q_2^2}{A_2^2} - \frac{Q_1^2}{A_1^2}$$

Knowing that the continuity principle

$$\frac{2g}{W}(P_1 - P_2) = Q^2 \frac{(A_1^2 - A_2^2)}{(A_1^2 \times A_2^2)}$$

$$Q = \frac{A_1 \times A_2}{A_1^2 - A_2^2} \times \sqrt{\frac{2g}{W}(P_1 - P_2)}$$

Since one knows the values of Q (32 ft./sec.^{2}) W = specific weight (62.4 lbs./ft.^{3}) and that the diameters of the meter. And these diameters and values one can determine a constant value for an individual meter.

Now we know that as the flow rate changes, the velocity changes proportionatly and as the velocity changes, the pressure changes.

That is as flow rate increases the velocity increases, and as velocity increases pressure decreases.

Therefore, in a Venturi meter, by knowing the change in pressure from the smaller area and the larger area one can determine the flow rate.

Problem 1: A Venturi meter has an input diameter of 6 inches and a small diameter of 3 inches. The input pressure (P_1) is 9 psi and the 3 in. (small area) pressure is 5 psi. (See diagram).

Calculate the rate of flow.

Solution

$$Q = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g}{W}(P_1 - P_2)}$$

$A_1 = .785 \times D^2$

$= .785 \times \left(\frac{6}{12}\right)^2$

$= .785 \times \frac{36}{144}$

$= .196$ ft.^{2}

$A_2 = .785 \times D^2$

$= .785 \times \left(\frac{3}{12}\right)^2$

$= .78 \times \frac{9}{144}$

$= .049$ ft.^{2}

$A_1 \times A_2 = .196 \text{ ft.}^2 \times .049 \text{ ft.}^2 = .01 \text{ ft.}^4$

$\sqrt{A_1^2 - A_2^2}$

$= \sqrt{(.196 \text{ ft.}^2)^2 - (.049 \text{ ft.}^2)^2}$

$= \sqrt{.036 \text{ ft.}^4}$

$= .189 \text{ ft.}^2$

$\sqrt{\dfrac{A_1 \times A_2}{A_1^2 - A_2^2}}$

$= \dfrac{.01 \text{ ft.}^4}{.189 \text{ ft.}^2} = .05 \text{ ft.}^2$

$g = 32 \text{ ft./sec.}^2$

$2g = 64 \text{ ft./sec.}^2$

$W = 62.4 \text{ lbs./ft.}^3$

$P_1 - P_2 =$

$Q - 5 = 4 \text{ psi or lbs./in.}^2$

$\sqrt{\dfrac{2g}{W}(P_1 - P_2)}$

$= \sqrt{\dfrac{64 \text{ ft./sec.}^2}{62.4 \text{ lbs./ft.}^3} \times 4 \text{ lbs./in.}^2}$

$= \sqrt{\dfrac{1.046 \text{ ft.}^4}{\text{lbs.} + \text{sec.}^2} \times \dfrac{4 \text{ lbs.}}{\text{in.}^2}}$

$= \sqrt{\dfrac{4.184 \text{ ft.}^4}{\text{sec.}^2 \times \text{in.}^2}}$

$= \dfrac{2.05 \text{ ft.}^2}{\text{sec.} \times \text{in.}}$

Since 1 ft. = 12 inches

Therefore

$\dfrac{2.05 \text{ ft.} \times 12 \text{ in.}}{\text{sec.} \times \text{in.}}$

$= 24.6 \text{ ft./sec.}$

$$Q = \frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g}{W} \times P_1 - P_2}$$

$Q = .05 \text{ ft.}^2 \times 24.6 \text{ ft./sec.}$

$= 1.23 \text{ ft.}^3/\text{sec.}$

Since A_1, A_2, g and W are constant for that particular Venturi method one can obtain the constant (K) and when the pressure changes one can multiply the constant by the $\sqrt{P_1 - P_2}$

Example: Using the Venturi meter in the previous problem, calculate the flow rate when

1. $P_1 = 11$ psi

   $P_2 = 5$ psi

2. $P_1 = 8$

   $P_2 = 3$

Solution

By obtaining the constant from

$$Q = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g}{W}} (P_1 - P_2)$$

$$\frac{A_1 A_2}{\sqrt{A_1^2 - A_2}} \times \sqrt{\frac{2g}{W}} \times \sqrt{P_1 - P_2}$$

$A_1 = .196 \text{ ft.}^2$

$A_2 = .049 \text{ ft.}^2$

$2g = 64 \text{ ft./Sec.}$

$W = 62.4 \text{ ft./sec.}$

Then substituting in the above equation

$$\frac{.196 \text{ ft.}^2 \times .049 \text{ ft.}^2}{\sqrt{(.196 \text{ ft.}^2)^2 - (.049 \text{ ft.}^2)^2}} \times \sqrt{\frac{64 \text{ ft./sec.}^2}{62.4 \text{ lbs./ft.}^3}} \times \sqrt{P_1 - P_2}$$

$$= \frac{.053 \text{ ft.}^4}{\text{sec.}} \times \sqrt{P_1 - P_2}$$

Since $P_1 - P_2$ is in lbs./in.^{2}

$$\frac{.053 \text{ ft.}^4}{\text{sec.}} \times \sqrt{\frac{(P_1 - P_2) \text{ lbs.}}{\text{in.}^2}}$$

Therefore,

$$\frac{.053 \text{ ft.}^4}{\text{sec.}} \times \frac{1}{\text{in.}} \times \sqrt{P_1 - P_2}$$

And 1 ft. = 12 in.

Then

$$\frac{.053 \text{ ft.}^3 \times 12 \text{ in.}}{\text{sec.} \times \text{in.}} =$$

K = .036 ft.^{3}/sec.

Now

1. $P_1 = 11$

   $P_2 = 5$

Therefore

$Q = K \times \sqrt{P_1 - P_2}$

= .636 ft.^{3}/sec. x 11 - 5

= .636 ft.^{3}/sec. x 2.45

= 1.56 ft.^{3}/sec.

2. $P_1 = 8$

   $P_2 = 3$

$Q = K \times \sqrt{P_1 - P_2}$

= .636 ft.^{3}/sec. x 8 - 3

- .636 ft.^{3}/sec. x 2.24

= 1.43 ft.^{3}/sec.

3. Friction

Friction is a force that exists between two substances that are interlocked, that is two substances that are in contact. A force that will retard motion of one substance across the other substance.

This friction force is created by two factors:

1. The first factor is the roughness of the two substances. It is easier to slide a block of wood on a wet surface than over a very rough surface.

2. The second such factor is the size of the areas of the two substances. It is a fact that weight also contributes to the friction force, but in water and wastewater the weight of the liquid in pipes is negligible.

This friction force is a disadvantage to plant operators since one has to move water through a piping system, the inside surface of the pipe and the water are in contact; therefore, the friction is present.

This friction force is a resistance that has to be overcome to be able to move the substance over the surface.

This resistance is called coefficient of friction, since one will be dealing with water. The coefficient of friction depends on:

1. The velocity of flow through the pipe.

2. The diameter size of the pipe.

3. The roughness of the pipe.

The coefficient of friction is a pure number. A pure number is 0.02, 0.1, 0.3 etc. That is the number has no unit value such as gallons, or $ft.^3$ or ft./sec. etc.

1. Since the coefficient of friction depends upon the velocity of flow through the pipe, this will indicate that as the velocity increases so does the coefficient of friction.

Let us look at a ball. The faster you bounce the ball, the greater number of times the ball hits the floor.

With the same idea in mind, let us visualize that water is made up of small balls. The faster you move the ball (water) the more times it will hit the side of the pipe, and therefore, the more number of times the friction will have to be encountered.

2. The second factor that will change the coefficient of friction is the size of the pipe. In this case, the larger the diameter of the pipe, the smaller the coefficient of friction, and the smaller the pipe the larger the coefficient of friction.

Let us visualize that water is made up of small balls. Now we know that velocity is a function of distance and time.

$$v = \frac{s}{t}$$

v = velocity

s = distance

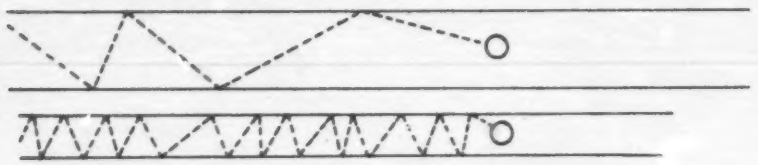
t = time

If velocity was at a constant rate and distance (s) was made larger than time (t) it has to get larger.

Example: A car travels at 55 mph. If the distance traveled is 110 miles than the time for travel was 2 hours.

Now if the velocity was the same 55 mph and the distance traveled was 270 miles, what is the time it took to travel? Ans. 4 hours.

Therefore, in a water system the larger the diameter of a pipe(s) the more time (t) is going to take for the water (ball) to hit the inside surface of the pipe and the bounceback and hit the other side. So the lesser number of times the water (ball) hits the sides, the less the number of times friction will be encountered.



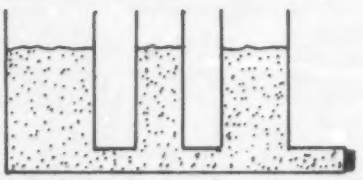
Therefore, the coefficient of friction will be smaller for larger pipes.

3. The third factor that effects the coefficient of friction is roughness of pipe. The rougher the inside surface of the pipe the higher the coefficient of friction and so the smoother the surface, the smaller the coefficient of friction. If you look at the surface of a pipe under a microscope you will see that the surface is very irregular and not smooth.

This roughness will effect the smooth flow of water and add friction. Again it is easier to slide a block on a wet surface than on a rough surface.

By taking all these factors effecting the friction one will come up with a value called coefficient of friction.* This coefficient of friction is the factor that has to be overcome so as an object could be moved by sliding.

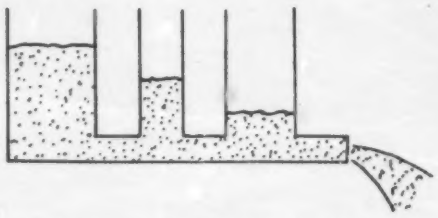
In water systems this coefficient of friction is considered friction loss. Friction loss is the amount of energy lost due to the friction. Let us look at a water system.



*Coefficient of friction value is usually provided to the student or can be obtained from charts obtained from manufacturers of pipe.

If the end of the system is closed, then we all know that water seeks its own level and so the level in Pipe A is the same as in B and C.

But let us remove the plug,



and one will experience that the level of water will drop in Pipe B and C. This drop in level of water line is due to the friction between the water and the inside surface of the pipe. This friction loss is either given as a coefficient of friction or as feet per 100 ft. of pipe.

Example: The friction loss for 100 ft. of pipe is .1 ft. What is the friction loss for the same pipe if the length is 5000 ft.

Solution

For every 100 ft. of pipe the loss in energy is equal to .1 ft. Then 5000 ft. = (50) 100 ft.; therefore, friction loss for 5000 ft. =

50 x .1 = 5 ft.

Glossary

Rate of Flow: Defined as the volume of liquid delivered in a unit of time. Expressed usually $ft.^3/sec.$ Symbol Q.

Bernoulli's Theorem: Defined as the energy possessed by a liquid system due to the potential head (L), velocity head and pressure head. This energy is constant through a liquid system.

Continuity principle: Defined as the volume of liquid entering a pipe at one end per unit of time must leave the other end in the same time.

Venturi meter: Defined as an instrument used to measure full liquid flow under pressure.

Friction: Defined as the force between two surface in contact that will retard the movement of one surface across the other. Expressed as a pure number. Symbol (Fl).

Problems

1. A pipe with a 12 inch diameter flowing full, with a velocity of 4 ft./sec. Calculate the rate of flow.

2. A 6-inch diameter pipe flowing full with a velocity of 5 ft./sec. Calculate the rate of flow.

3. A 12-inch diameter pipe flowing half full with a velocity of 4 ft./sec. Calculate the rate of flow.

4. A velocity through a channel is .5 ft./sec. The cross-sectional area of the channel is triangular in shape (See Diagram). The base of the triangle is 3 ft., the water depth is 1.5 ft. Calculate the flow rate through the channel.

5. Two connected water mains, the input diameter is 6 inches and the output is 8 inches. The velocity of the liquid in the input line is 10 ft./sec.
   1. Calculate the rate of flow through the system.
   2. Calculate the velocity at the output end.

6. A horizontal section of pipe has two diameters. The first is 8 inches and the second 12 inches. If the liquid flow through the first diameter is 80 $ft.^3/sec.$, calculate:
   1. Velocity in the small diameter.
   2. Velocity in the second diameter.

7. A venturi meter is inserted into the horizontal section of a water line whose entrance is 18 inches. Find the flow rate of water if the throat diameter is 12 inches. The difference in pressures is 30 psi.

8. In problem number seven (7), if the pressure difference at

   8:00 a.m. = 15

   10:00 a.m. = 25

   11:00 a.m. = 20

   12:00 noon = 22

   1:00 p.m. = 28

   3:00 p.m. = 34

   Calculate the flow rates at the different hours.

9. The gauges read P_1 = 12 psi and P_2 = 9 psi. The diameters of a venturi meter are 5 in. and 2 in. respectively. Calculate:

   1. Velocity in the main line.
   2. Flow rate
   3. Velocity in the small diameter.

10. The coefficient of friction for a 12 in. diameter pipe is .2 ft./1000 ft. Calculate the friction loss at:

    1. 5000 ft.
    2. 10,000 ft.
    3. 360 miles 1 mile = 5280 ft.

Additional Reading

Ewen, Nelson, Schurter, McFadden, Physics for Career Education, Prentice Hall Publishers, Chapters 2, 3, 9, 10, 15.

Subject Areas of Interest

1. Area
2. Cross-sectional Area
3. Velocity
4. Work
5. Power
6. Enerty (Static, potential and kinetic)
7. Friction
8. Pressure
9. Total force exerted by liquids
10. Bernoulli's Theorem

The concepts covered in the section temperature and heat are:

1. Fahrenheit scale
2. Celsius scale
3. British thermal units (BTU's)

These concepts are prevalent in the water and wastewater technology in such areas as:

1. Sludge digestion
2. Settling rates of solids
3. Solubility of solids
4. Bacterial activity
5. Odor control
6. Thermal pollution

TEMPERATURE AND HEAT

The role remperature plays in water and wastewater technology is important. Changes in temperature can

1. Effect the solubility of matter (solids, liquids, and gases) in water.

2. Effect the settling rate and sedimentation of solids in a water system.

3. Effect the coagulation rate and characteristics of coagulants in a water system.

Temperature

Temperature is the measure of hotness or coldness of an object (water included as an object). This hot object is a something that has absorbed energy which man can identify by merely being close to or touching the object. The absorbed energy can be felt. Since an individual is influenced to the energy differently than another, an important way was established.

Since water was the most abundant chemical on earth, easily available and also changed forms (ice, solid, water, liquid, and steam vapor), it became the standard.

Two basic scales were developed:

The first being Celcius (Centigrade). This scale provided the references 0^{o} C. (zero degrees) being the ice point and 100^{o} C. (100 degrees) being the boiling point.

The second being the Fahrenheit. This scale provided the references 32^{o} F. (32 degrees) being the ice point and 212^{o} F. (212 degrees) being the boiling point.

The relationship between Celcius and Fahrenheit is

$$C = \frac{5}{9} (^{o} F. - 32)$$

$$^{o} F. = \frac{9 \times {}^{o} C.}{5} + 32$$

Example 1: What is the temperature in ^{o} C. if the Fahrenheit reading is 45?

Solution

$$^{o} C. = \frac{5}{9} (^{o} F. - 32)$$

$$= \frac{5}{9} (45 - 32)$$

$$= \frac{5}{9} \times 13$$

$$= 7.2^{o} C.$$

Example 2: What is the temperature of 20^{o} C. in Fahrenheit?

$$^{o} F. = \frac{9}{5} \times {}^{o} C. + 32$$

$$= \frac{9}{5} \times 20 + 32$$

$$= 36 + 32$$

$$= 68^{o} F.$$

Heat

The difference between temperature and heat is that temperature provides a value in relation to the ice point 32^{o} F. and boiling point 212^{o} F. Heat indicates the amount of energy an object contains. This energy can be increased or decreased by the addition of more heat or removing more heat.

The measurement of heat is BTU, British Thermal Unit. This means that by raising the temperature of 1 lb. of water 1^{o} F., 1 BTU of heat is required.

Example 1: To raise the temperature of 1 lb. of water 10 degrees, 10 BTU's of heat is necessary.

Example 2: To lower the temperature of 1 lb. of water 20 degrees, 20 BTU's will have to be removed from the 1 lb. of water.

Problem 1: 50 lbs. of water have a temperature of 50° F. How many BTUs are needed to raise the temperature to 120° F.?

Solution

120° F. - 50° F. = 60° F.

If the BTU's to raise 1 lb. of water 1° F. then 60° equal

60° F. x 1 = 60 BTU's

But the problem states 50 lbs. of water

Then

60 BTU's x 50 = 3000 BTU's

Problem 2: A sludge digestor with a content of 150,000 lbs. of sludge has to be heated from 85° F. to 100° F. Calculate the amount of BTU's needed.

Solution

ΔT (change in temperature = 100° F. - 85° F.)

ΔT = 15° F.

150,000 lbs. x 15° F. = 2,250,000 BTU's

Problem 3: Assume that the temperature in the digestor in Problem 2 drops ½° F. for every hour. What is the total BTU's needed to maintain 100° F.?

Solution

The total degrees of temperature lost in one full day is 12° F.

½° F. drop/hour

12° F. drop/24 hours

BTU's = lbs. x D T

= 150,000 lbs. x 12^{0}

= 1,800,000 BTU's

Specific Heat

Since other substances react differently to heat than water does, than the value of BTU changes for each element or substance.

Example: Steel has a BTU value of 0.117.

That is the amount of heat required to raise 1 pound of steel 1^{0} F. is 0.117 BTU's.

So the equation used to determine BTU's is

Q = CMDT

Q = Heat required in BTU's

C = Specific heat (BTU/16 - ^{0} F.)

M = Mass in lbs.

DT = Change in temperature degrees

Problem: Specific heat of iron is 0.11 BTU/lb. - ^{0} F. The weight is 5000 lbs. The temperature rise is 35 degrees. Calculate the BTU's used.

Q = CMDT

= .011 BTU/lb - ^{0} F. x 5000 lbs. x 35^{0} F.

= 19250 BTU

Glossary

Temperature: The property of a body of matter that causes one to experience a sensation of hot or cold when we touch it.

Thermometer: A device for measuring temperature. Expressed usually by one of two scales.

1. Fahrenheit

Additional Reading

Ewen, Nelson, Schurter, McFadden, Physics for Career Education, Prentice Hall Publishers, Chapter 2, 16 through 19.

Subject Areas of Interest

1. Volumes
2. Temperature
3. Heat
4. Heat Transfer
5. Specific Heat
6. Thermal Expansion of Solids and Liquids
7. Gas Laws
   a. Charles "Law"
   b. Boyle's Law
   c. Charles' and Boyle's Law Combined
8. Fusion
9. Vaporization

Problems

1. Change
   a. 160^{o} F. to ^{o} C.
   b. 68^{o} F. to ^{o} C.
   c. 40^{o} C. to ^{o} F.
   d. -12^{o} C. to ^{o} F.
   e. 4^{o} F. to ^{o} C.
2. Calculate the BTU's needed to raise the temperature of 280 lbs. of water from 68^{o} F. to 100^{o} F.
3. The water temperature is changed from 54^{o} F. to 160^{o} F. If 627,200 BTU's was used, what is the weight of the water? Specific heat of water is 1.00.
4. A section of pipe weighs 600 lbs. The temperature rose 62 degrees. The specific heat of the pipe is 0.112 BTU's. Calculate the BTU's absorbed by the pipe, excluding any heat loss.
5. What is the BTU/Day needed to maintain the temperature of sludge at 98^{o} F. in a digestor (full) with dimensions of 25 ft. radius, 20 ft. height. If the sludge loses 2 degrees/hour. The specific heat of sludge is 1.00. 1 cu. ft. of sludge weighs 64.2 lbs.

The concepts covered in the section electricity are:

1. Magnitude of current (amps)
2. Resistance (ohms)
3. Voltage
4. Horsepower
5. Watts/Kilowatts

These concepts are prevalent in the water and wastewater technology in such areas as:

1. Power consumption
2. Motor efficiency
3. Liquid flow
4. Preventative maintenance

ELECTRIC CURRENTS

Electric currents are electric charges in motion. These electric charges are due to the make up of matter. Since matter is made up of elements (chemical definition) and elements are composed of electrons having a negative charge, protons having a positive charge and neutrons having a neutral charge. By looking at a model of an element one will see that the neutron and proton are "housed" inside a shell. Example to illustrate neutrons and protons pump two types of gases into a ball.

Now since the protons have a positive charge to them then this ball will have a positive charge and since elements are usually in a neutral condition then it stands to reason that around the ball better known as a nucleus will be negative charges so as to neutralize the positive charge. These negative charges are called electrons.

Now since pure matter (solids, liquids, or gases) are made up of a concentration of like elements, these electrons are moving through the matter in any direction.

If one places a force on one side of the matter and suppose this force is a concentration of electrons, then electrons from the matter will have to be removed from the other side.

This force can be measured for its rate of addition and removal, the amount of resistance encountered and amount of power applied. Since one can provide a force unto matter at one end and retrieve the force on the other, then one can use a force or energy generated in one place and used in another place.

Matter that allows this free movement of energy is classified as conductor. There are good conductors, fair conductors, and poor conductors. Poor conductors are also called insulators. That is they resist the movement of electrons through that particular matter.

Since this electric current is flowing through a matter in this case copper wire, certain factors effect this flow. These factors are (1) magnitude of current, (2) the resistance encountered by the current (3) potential difference between the start and end of the current.

1. The magnitude of current: The magnitude of current is defined as the rate at which an electric charge passes a given point. This is measured in amperes. Since rate is the volume divided by time then one can say

$$I = \frac{v}{t}$$

I = Rate amps

v = volume

t = time

The unit values in electricity are usually named after the scientists that discovered the ratio.

I = Amps (Amperes)

g = coul. (Coulomb). Derived from the fact that (electron has a charge of 1.6 x 10 - 19 coul.

Therefore, an ampere indicates that 6.3×10^{18} electrons per second "flowed" past a point.

Since an electric demand may be more than the system may be able to deliver, then the safety installed in the system is the fuse or breaker.

The continuity principle applys in electricity also. That is what volume enters the wire, the same volume will have to be discharged. This

discharge could be in different forms. The most common is to transform this energy from kinetic to mechanical. That is to change electricity to drive an electric motor.

So if one is only putting a flow rate of 10 amps in the wire, and the demand for the electric motor hooked to the wire is 15 amps, then the continuity principle indicates that the system will break down. That is the demand is greater than the supply.

2. The resistance. Since electrons have to move through matter, they encounter a resistance. All matter has some resistance to electric current. Some are more resistant than the others. This, the resistance of matter, can be used to the advantage electrical system in transformation of electric current to mechanical energy or to retard or stop the movement of current.

This resistance has a unit value of ohms and is dependent on several factors. Among these are:

a. Temperature. An increase in temperature increases the resistance.

b. Length. The resistance increases directly with the length.

c. Cross-sectional area. Resistance varies inversely with cross-sectional area.

d. Material. The nature of the material is a factor.

3. Potential difference between the start and end of current. To be able to make the electrons move from one end of the wire to the other end one must apply a force. This force or "push" is measured in volts. When this force is applied a negative and positive sides are formed which therefore have a potential difference known as voltage.

Example in a column of water since there is a difference of height from the surface of the water and the bottom this difference in height provides a potential energy which can be transformed to pressure.

Let us look at a battery. The battery has a positive pole and a negative pole. By saying that the battery has 1 volt, it means that the strength of the battery is 1 volt. That is the difference of the number of electrons between the positive (+) pole and the negative (-) pole is 1 volt.

It takes 1 unit of energy (joule) to move 1 coulomb of charge from one point to another. That means the flow of electrons is from negative pole to positive pole with a force of 1 volt.

By interacting the concepts of amperes, voltage and resistance, a German scientist named George Ohm was able to show a constant relationship between the three concepts. This relationship is

$$I = \frac{v}{R}$$

I = Current, amperes

v = force voltage

R = Resistance ohms

Example 1. A wire has a resistance of 10 ohms and carries a voltage of 30 volts. Calculate the current in the wire.

Solution

$$I = \frac{v}{R}$$

I - current

v = voltage

R = resistance

$$I = \frac{30 \text{ volts}}{10 \text{ amps}}$$

$$= 3 \text{ ohms}$$

Example 2. If a unit has a draw current I of 5 amps and is attached to a 120 volt power source, calculate the resistance of the unit.

Solution

$I = \frac{v}{R}$

So $v = IR$

and $R = \frac{v}{I}$

$R = \frac{120 \text{ volts}}{5 \text{ amps}}$

$= 24$ ohms

R = Resistance

v = voltage

I = current (ohms)

USES OF ELECTRIC CURRENT

The uses of electric current are varied. The most common use is to drive electric motors. The motor will perform work. The rate at which work is being done is called power. If an amount of work (w) is done in a period of time (t), the power involved is

$P = \frac{w}{t}$

P = Power watts

w = Work joules

t = time sec.

Power also is measured in horsepower (hp).

1 horsepower = $\frac{500 \text{ ft.-lbs.}}{\text{Sec.}}$ or $\frac{3300 \text{ ft.-lbs.}}{\text{Min.}}$

A correlation between watts and horsepower is established.

1 horsepower (hp) = 746 watts

Now let us convert electric power to mechanical power. Since we know that it takes one (1) unit of energy (joule) to move 1 coulomb of charge from one point to another to produce a volt, then it stands to reason that

$v = \frac{w}{g}$

v = volume
w = work joules
g = coulomb

Since

$P = \frac{w}{t}$

P = Power watts
w = work (energy) joules
v = voltage
g = charge. cpi;p,bs
t = time sec.

And

$w = v \times g$

Then

$P = \frac{v \times g}{t}$

But we also know that

$I = \frac{g}{t}$

I = current amps
g = charge coulombs
t = time sec.

Then

$P = v \times I$

Several variations of being able to determine P (watts) can be found using

1. $P = v \times I$

2. $v = I \times R$

Two such variations are

1. $P = I^2 R$

   $P = \frac{v^2}{R}$

Example: 140 ohm resistor is rated at 8 watts.

Calculate

1. Current in amps

2. The voltage

Solution

1. $P = I^2 R$

$$I^2 = \frac{P}{R}$$

$$I = \frac{P}{R}$$

$$= \frac{8}{140}$$

$$= .057$$

$$= 0.24 \text{ amps}$$

2. $P = vI$

$$v = \frac{P}{I}$$

$$= \frac{8 \text{ watts}}{0.24 \text{ amps}}$$

$$= 33.3 \text{ volts}$$

Example 2.

Problem: An electric motor draws a current of 8 amps and is connected to a 120 volt power supply. Calculate the horsepower of the motor. (Neglect efficiency).

Solution

$P = v \times I$

= 120 volts x 8 amps

= 960 watts

Since 1 hp = 746 watts

Then $hp = \frac{\text{watts}}{746 \text{ watts}}$

$$= \frac{960}{746}$$

= 1.28 hp

The concept in Example 2 of motor efficiency. Since no mechanical unit is 100% efficient, that is the power or work put into a motor is not the actual power or work delivered by that motor. The difference in input and output is due to:

1. Generation of heat.
2. Resistance in the electric wires in the motor.
3. Friction due to rotating shafts.

These are another form of energy than mechanical and cannot be utilized in that motor to do work that is necessary. The manufacturer will provide an efficiency curve for that motor at specific work and power loads.

Therefore, in Problem No. 2, if the motor was 90% efficient, what would the actual hp delivered by the rotating shaft

Actual delivered hp = operating hp x efficiency

hp = 1.28 x 0.90

= 1.15 hp

Glossary

Electrical current: Electrons moving through matter.

Amperes: The magnitude of current placed in a system that is the amount of electricity. Expressed in amps. Symbol (I).

Coulombs: A charge given by 6.3×10^8 electrons expressed in coulombs. Symbol (coul.)

Voltage: The amount of force (power) placed on a system to provide a change between its ends. Expressed in volts. Symbol (v).

Resistance: The resistance offered by the system against the flow of electric current. Expressed in ohms. Symbol (R).

Power: The rate of work done in a unit of time, or the potential work that can be done in a unit time. Expressed in watts or horsepower. Symbol P.

Ratio of horsepower to watt

Expressed as

1 hp = 746 watts

or

1 hp = .746 Kw (Kilowatts)

Additional Reading

Ewen, Nelson, Schurter, McFadden, Physics for Career Education, Prentice Hall Publishers, Chapters 9 & 20 through 29.

Subject Areas of Interest

1. Work
2. Power
3. Energy
4. Static Electricity
5. Direct Current Electricity
6. ohm's Law and DC Circuits
7. DC Sources
8. Generators
9. Motors
10. Alternating Current Electricity
11. Transformers
12. Alternating Current Circuits

Problems

1. A resistor draws a current of 16 amps and is connected to a 110 volt supply. Calculate the power (P) in kilowatts.

2. A resistor operates on a 115 v. line. If the resistance is 15 ohms, what current does it draw?

3. An electric heater draws a maximum of 11.5 amps. If its resistance is 18.5 ohms, to what voltage should it be connected to?

4. An electric motor draws a current of 4 amps and is connected to a 110 volt line. Calculate

   a. Power in watts

   b. Horsepower

5. How many amperes will a 100 watt lamp on a 110 volt line draw?

6. How many amperes will a ½ horsepower motor on a 120 volt line draw?

7. A motor draws a current of 14 amps and is connected to a 240 volt line. If the motor efficiency is 90%, calculate the actual delivered horsepower.

8. The motor in Problem 7 is now drawing 15 amps of current. The actual delivered horsepower is the same. Calculate the new efficiency.

9. A motor draws 10 amps of current. It has a resistance of 12 ohms. Total number of hours it operates is 14 hours. Calculate

a. Voltage of the system.

b. The power (watts) the motor uses.

c. The operating horsepower.

d. The total watts consumed.

e. The total operating cost, if the cost/kw-hr. is $.12